

Honeywell International Inc., Ceramic Components  
(formerly AlliedSignal, Inc.)

## Innovative Molding Technique to Produce Ceramic Turbine Components

*In the mid-1990s, U.S. manufacturers in the turbine component industry wanted to develop ceramic industrial turbine components that would be lighter, longer lived, and more heat-resistant (permitting greater fuel efficiency and less pollution) than the alloy components in use at that time. Traditional molding techniques for ceramic turbine components required custom machine work and could not generate enough savings to achieve production costs equivalent to super alloy components that would enable marketplace penetration. It was estimated that foreign firms had a two- to three-year head start into researching and developing ceramic components for turbines and that they would soon produce ceramic parts that would overcome this cost barrier, consequently shrinking U.S. manufacturers' market share.*

*Honeywell International Inc., Ceramic Components (formerly AlliedSignal, Inc.) submitted a proposal to the Advanced Technology Program's (ATP) 1995 focused program competition for "Materials Processing for Heavy Manufacturing". The company proposed to develop and refine a ceramic molding process called "aqueous injection molding" (AIM) to achieve low-cost fabrication of silicon nitride ceramic components.*

*At the completion of the ATP-funded project, Honeywell had successfully implemented the AIM process improvements, which then required engine test validation funding to lead to commercial production of ceramic turbine splitter vanes. However, the process was unable to reliably mold aircraft engine turbine blades.*

### COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

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Research and data for Status Report 95-07-0003 were collected during October - December 2001.

### U.S. Manufacturers Losing Ground to Foreign Competitors

In 1995, structural ceramics were seen as relatively high-cost, high-performance materials that could provide significant improvements in efficiency and performance, as well as reduce emissions and pollution. These improvements could substantially increase the domestic and international market share of U.S. heavy equipment manufacturing firms. However, unless the cost of producing structural ceramics dropped significantly, the material would not be adopted in turbine engines, and these improvements would not be realized. Foreign manufacturers had begun research

into structural ceramics in the early 1990s and were several years ahead of U.S. manufacturers. U.S. firms feared that the cost of foreign-based manufacturing would continue to decline, which would increase the foreign-based market share in this growing industry.

### New Technology Could Increase U.S. Market Share

The focus of Honeywell's ATP project was to develop an aqueous injection molding (AIM) process that could achieve a tenfold reduction in the cost of silicon nitride turbine blades for industrial turbine engines. A number of complex-shaped silicon nitride components were being fabricated at Honeywell in small volumes (under

100 parts per order) before the start of the ATP-funded project. However, the existing process used to produce these parts involved slip-casting parts larger than necessary in plaster molds with extensive machining of "green" bisque stock. This resulted in costs that were 10 times higher than what the market would bear. These high manufacturing costs were due to extensive processing labor, low overall process yields, high equipment costs, and the machining of extensive amounts of waste material that could not be reused.

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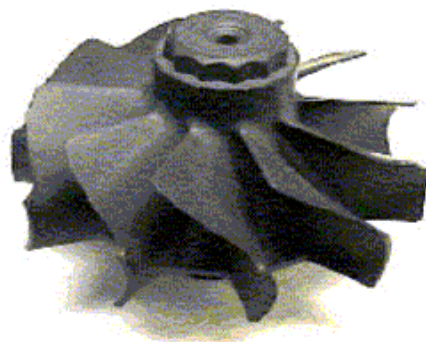
***This process would have a significant impact on the industry's ability to manufacture high-quality, complex, ceramic components at low cost and with higher yields.***

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Honeywell's proposed process would form components close to the final shape of the part to minimize custom machining and wasted raw material. It was expected that the successful development of this process would have a significant impact on the industry's ability to manufacture high-quality, complex, ceramic components at low cost and with higher yields. The initial target application was to produce cost-effective silicon nitride components in industrial gas turbines and turbo-alternators. The end users in the utility power and transportation industries would be the ultimate beneficiaries, because ceramic component implementation in these applications would lower component costs, increase performance and efficiency, and decrease nitrogen oxide and carbon dioxide emissions. Moreover, Honeywell asserted that the successful development of the AIM technology would place U.S. companies in a competitive or superior position for manufacturing heavy-duty engines for vehicles, aircraft, and power plants. This improved position in the engine manufacturing market could lead to an increase in employment in the United States.

### **Technology Has Potential for Wide-Ranging Economic Impact**

Honeywell applied to ATP for cost-shared funding under ATP's 1995 focused competition in "Materials Processing for Heavy Manufacturing". ATP funding was sought to accelerate the process improvements to AIM.



The existing process required custom machining of "green" bisque ceramics.

Before the start of the ATP-funded project, government and industrial studies had identified advanced materials, including structural ceramics, as critical technologies for maintaining U.S. economic strength in the manufacturing sector. Structural ceramic components were already in production in the United States for applications such as cutting tools, heat exchangers, filters, and heat engine components. The market was expected to grow at a rate of 10 to 15 percent annually for the next decade. However, two foreign companies were ahead of U.S. manufacturers in the research and development of the advanced materials used in turbines and turbo-alternators. Without significant improvement by U.S.-based industries, the nation's manufacturing market share in heavy equipment was expected to decline. On the other hand, if Honeywell were able to successfully develop an AIM process, U.S. manufacturers could use these components to gain a competitive edge in major manufacturing markets such as chemicals, construction, electronics, power generation, environmental controls, aircraft, recreational goods, and surface transportation.

### **Honeywell Identifies Technical Barriers to New Technology**

Significant technical issues needed to be addressed during the ATP-funded project in order to achieve the tenfold reduction in costs for silicon nitride complex-shaped components. The five most significant barriers were:

1. Producing feedstock with consistent and stable properties
2. Consistently forming the feedstock into void-free pellets

3. Developing a mold design that would assure complete mold filling while minimizing defect formation and uniform packing to minimize distortion during sintering
4. Creating a consistent injection-molding process to achieve reproducible, defect-free molded components (e.g., no voids, no leaks, no cracking)
5. Minimizing cycle times

Solving each technical barrier would be considered incremental improvements. The challenge, however, of integrating all of the individual improvements into a process that ran without human intervention, with 80 percent fewer cycle steps and generating a tenfold cost reduction, was daunting and risky. It was precisely this challenge that Honeywell needed to meet to remain competitive and even to surpass foreign manufacturers.

### **Project Research Plan Specifies Three Critical Development Tasks**

The Honeywell research plan defined three tasks to be completed over a 27-month period:

1. Refine the AIM technology for silicon nitride to achieve consistent high yields. This meant refining individual process steps and developing and implementing improved intelligent process controls to optimize the silicon nitride AIM fabrication process.
2. Operate the optimized AIM fabrication process for 12 months to evaluate the process's capability and to make further refinements based on process output results.
3. Evaluate a number of the components manufactured during task two; this work would be performed by Solar Turbines, a purchaser of turbine blades for industrial engine use. Solar Turbines would perform a 500-hour engine test to determine component performance, quality, and consistency.

### **Project Encounters Both Unexpected Barriers and Successes**

Tasks one and two started as planned but later experienced some problems and caused delays that extended the period of performance for Honeywell

during the course of the ATP-funded project. The preparation process for AIM feedstock, the actual molding mixes, and the mold designs created during tasks one and two led to improvements in flow and stability, as well as reduced cracks. However, the team still found cracks in the parts, unfilled spaces, and distortion. Although they continued testing, adjusting feedstock, and upgrading a number of parts, the following three technical problems remained, which made it difficult to achieve the dimensional accuracy required:

1. Bulging part platforms and bases due to feedstock/binder problems
2. Part distortion due to poor powder packing
3. Lot variation in feedstock and molding performance

By the close of the ATP-funded project in 1998, Honeywell had achieved a 52.7-percent yield of turbine blade parts with no defects, but still had consistent problems with cracked or deformed blades. The parts' size and geometry were not suitable for the AIM process. Therefore, Honeywell experienced difficulty in achieving engine quality hardware for Solar Turbines to insert into the engine and complete the performance test.

Nevertheless, the team was able to develop the following key criteria for parts that could be made cost effectively using the AIM process:

- Parts with a maximum dense cross-section less than 0.25 inches
- Parts that can be constrained to a specific shape during densification
- Complex, small parts less than 2 inches in any dimension
- High-volume, complex-shaped components
- Parts that cannot be made in other ways

Although the team was not able to complete the project, they did predict production costs for a turbine blade, assuming the technical performance requirements could be met. Solar Turbines requested a quotation for

5,000 blades per year at a price of less than \$200 each. Based on a volume of 7,500 per year to allow for defects, the slip-casting/machining method would cost approximately \$436 each. AIM would cost \$175, a savings of 60 percent. The potential for success existed.

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After the conclusion of the project, the AIM technology did allow the company to manufacture some small, complex parts, such as diffuser splitter vanes for potential use in commercial aircraft engines, which they had been unable to form prior to the ATP-funded project. The original aluminum part had an erosion problem, which would benefit from the harder, more wear-resistant silicon nitride replacement. Estimated potential annual production sales were \$140,000. Honeywell also worked with power-generation turbine companies to evaluate additional components, such as blades and nozzles. Honeywell Ceramic Component's production unit grew from 4 percent of sales in 1995 to 38 percent of sales in 1998.

### **Honeywell Shares Project Knowledge**

During the ATP-funded project, Honeywell shared its knowledge and prototypes with Solar Turbines and published technical information about the AIM technology in the *American Ceramic Society Bulletin*, the *Journal of the American Ceramic Society*, and in the *American Society of Mechanical Engineers' Journal of Applied Mechanics*. Honeywell presented information about its technical achievements at the International Gas Turbine Conference, the American Ceramic Society Annual Meeting, and the American Society of Mechanical Engineers Turbo Expo. As a result of the ATP-funded project, Honeywell reported being two to three years ahead of where it would have been in the development and refinement of AIM without ATP support. Thus, if the project had been more successful, it could have assisted in closing the research gap with foreign competition as well as putting Honeywell and its

customers in a position to challenge foreign-based competitors and increase U.S. manufacturing market share.

### **Conclusion**

Honeywell successfully utilized the aqueous injection molding (AIM) process to fabricate ceramic splitter vanes in 1998, after the close of the ATP-funded project, and had plans to obtain funding for engine qualification testing. They also developed plans to commercialize other small, complex high-volume ceramic turbine components, such as nozzles and blades. Consistent technical problems with the larger turbine blades, however, stalled the original project at the prototype stage due to cracking and distorting. Eventually, with continued research, Honeywell planned to use the AIM technology in making varied components like nozzles and blades, as well as unique wear parts for microturbines and stationary turbines.

## PROJECT HIGHLIGHTS

### Honeywell International Inc., Ceramic Components (formerly AlliedSignal, Inc.)

**Project Title:** Innovative Molding Technique to Produce Ceramic Turbine Components (Aqueous Injection Molding for Low Cost Fabrication of Silicon Nitride Components)

**Project:** To develop and refine an aqueous injection molding (AIM) process for low-cost silicon nitride components, enabling their use in high-performance turbine engines for auxiliary power units and other turbo machinery, such as stationary power-generating systems.

**Duration:** 9/30/1995-9/29/1998

**ATP Number:** 95-07-0003

#### Funding (in thousands):

ATP Final Cost	\$ 738	40%
Participant Final Cost	<u>1,128</u>	60%
Total	\$1,866	

**Accomplishments:** This ATP-funded project assisted Honeywell, a major U.S. manufacturer of ceramic components, in furthering its ceramic processing research knowledge. This eventually closed the three-year research gap between Honeywell and its foreign-based competition. As a result of its ATP-funded research, in 1998, Honeywell successfully implemented the AIM process improvements for ceramic splitter vanes. After the close of the project in 1998, Honeywell planned to devote several million dollars over the next 5 to 10 years to overcome the remaining technical barriers to the aqueous injection molding of small ceramic turbine components and wear parts for microturbines and stationary turbines.

In order to share some of the knowledge gained during the ATP project, Honeywell published information about its technical achievements in several engineering journals and presented its findings at three conferences during the course of the research.

**Commercialization Status:** As a result of its research into AIM, Honeywell implemented process improvements for the fabrication of ceramic splitter vanes, a part that the company was not able to fabricate before the start of the ATP-funded project. They had plans to commercialize other small, complex, high-volume parts like blades and nozzles. The Ceramic Components Unit of Honeywell increased production from 4 percent of sales in 1995 to 38 percent in 1998.

**Outlook:** Through the ATP-funded project, Honeywell recovered research and development time lost to foreign-based competitors and was able to fabricate one ceramic component produced by AIM. Manufacturing additional complex parts will require more development time, and there is still some uncertainty whether AIM will result in the manufacture of a substantial number of turbine parts. Small size, complexity, and high sales volume will be the keys to cost effectiveness. The outlook for this technology is uncertain.

**Composite Performance Score:** \* \*

**Focused Program:** Materials Processing for Heavy Manufacturing, 1995

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